Lego Robotics as a Tool for Guided Discovery: Learning gearing concepts with Lego Mindstorms

Savanna Jamerson
Ron Austin
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Problem/Goal – What we intended to do and why it was important

Our research team began with a question regarding the discovery learning process. We hypothesized that guided discovery within a community of learning was a more effective approach to teaching about velocity and torque then discovery learning in isolation, or without guidance (or the use of traditional methods of teaching such as lecture and note taking).

We began with the question: "Can guided discovery educational methods be effective in teaching students concepts that can be applied to real world situations"? We extended this question to: "Can such guided discovery be used to teach students gearing concepts through the use of Lego Mindstorm Robotics"? Our purpose was to test the effectiveness of guided discovery learning as an instructional tool while utilizing technical objects that students could "play" with. Thereby attempting to motivate students to sustain interest and focus while learning. We also hypothesized that students would understand the gearing concepts thoroughly if asked to apply those concepts to a real life situation. We designed a lesson for these purposes and in doing so we realized that another purpose of our research was operational. We realized that we could learn from the research activity how to best revise the lesson and to make it more effective.

This question of guided discovery learning within a learning community is an important one since it tests the validity of the ecological psychology framework, which postulates that when groups of people engage in intellectual activities in a natural setting, natural distributions of cognitive activity will occur. As educators, we wanted to learn how to best structure and design the natural setting so that the optimal learning experience would occur.

Literature Review and Tested Hypotheses

Bell and Winn's Chapter entitled, "Distributed Cognitions, by Nature and by Design   proposes that researchers look at the distributed learning environment as a dynamic system in which change is always occurring due to the interactions of the participants with the environment and all of its components. In our activity with Lego Robotics, we focused on this interdependence and complex interaction of the "system" components in an effort to follow the "self-organizing" process of the learning community so that the community ultimately reached the "agreement over an understanding" or "steady state"(4). We thought this worth testing and observing since this is an essential step toward the successful facilitation of the natural distribution of cognition. We were able to observe how our participants interacted with each other as well as with the artifacts and instructors in order to reach this steady state so that the learning activity worked for them. As researchers and the designers of the lesson, we were hoping to learn how to best nurture and enhance the achievement of this "steady state." Also suggested in this chapter, Bell and Winn point out the importance of the system components being flexible or open to change in order to achieve self-organization, including the artifacts that are included in the system (5). The Lego Robotics kit lent itself to such change and flexibility perfectly. The use of gear parts allowed students to make changes to a pre-built robot using different gear sizes in order to test their understanding of gears by applying what they had learned. We were able to observe how the flexibility of the artifacts, that is the different gears, enhanced the self-organizing process as our participants negotiated the use of proper gear sizes that should be used.

We also read excerpts from Seymore Papert's book *Mindstorms*. Papert is especially relevant to Lego robotics since he is the creator of the Logo programming language, in which Robolab, the robotic programming software, is partially based. In chapter 2: Mathophobia the fear of learning, Papert writes that he and his colleagues have developed three principles that have given more structure to the concept of an appropriate way to teach mathematics. The second principle is the "the power principle" which he defines as empowering the learner to perform personally meaningful projects that could not be done without it. Rather than having students perform (seemingly) irrelevant algorithms through the use of pencils and paper he advocates a learning that is based in real life activities.

Papert gives an example of a student learning nouns and verbs by using a computer program where they create random poetry- poetry from random words. One student, with previously low scores in grammar, "was showing evidence of learning" through this activity. It was apparent that her difficulty with grammar was not due to an inability to work with logical categories. It was something else. She had simply seen no purpose in the enterprise. She had not been able to make any sense of what grammar was about in the sense of what it might be for. When she was generating poetry she started to classify her words into categories (classes). She learned that words can be placed in "different groups or sets and that can work for her"(49).

Papert's observations are reinforced by Brown, Collins, Duguid (Situated Learning and the Culture of Learning). "People generally learn words in the context of ordinary communication. This process is startlingly fast and successful. By listening, talking and reading the average 17 year old has learned vocabulary at a rate of 5,000 words per year (13 per day)…Definitions of words are "self contained" pieces of knowledge. But words are not islands" (2). By building functioning robots and experimenting with gears to adjust the velocity and torque students will be taking part in a real and meaningful project. They will be able to categorize their knowledge of ratios and gears. We also see the robotics project as being related to Brown,Collins, and Duguids "cottage cheese example" where the dieter off loaded part of the cognitive task onto the environment. The dieter used his environment to help solve the problem as we expect to be the case with our students.

Ann Brown's, "Design Experiments: Theoretical and Methodological Challenges in Creating Complex Interventions in Classroom Settings" is also relevant to our research project since Brown prompted our team to avoid what she terms "inert knowledge." Brown defines this concept as knowledge that students are unable to apply appropriately to the real world, even though they may seemingly 'know' that knowledge. We did not wish to test this concept since as experienced teachers, we already know this to be a very real outcome of learning and instruction. Instead, we hoped to test our instructional methods and lesson plan to ascertain its value in avoiding such outcomes of inert knowledge. The Lego Robotic exercise required our student participants to rebuild the gearing system of a pre-built robot in order to apply knowledge of gears that we wished to teach them. Students were given the specific goal of making the robot climb a ramp by reconfiguring the gearing system. This was an application of Brown's prescription for methods of assessment that require students to discover and use knowledge rather than simply retain knowledge. In addition, through Brown's research in guided instruction and assessment in social contexts, we aimed for an activity that would allow for a "forum for externalizing simple comprehension" as well as encourage self-reflective learning and critical inquiry" (150). Hence, the activity called for small group interaction as well as a set of group activities and reflection questions that were to be completed through group consensus. Brown prescribes the teachers role as, "to act as active role models of learning, as responsible guides to students' discovery process. They teach on a need-to-know basis, responsive to students' needs" (150). Our robotics gearing activity followed this prescription as well, interjecting only when students needed an 'expert' voice to put them back on track. Like Brown, we too attempted to follow the Vygotskian notion of the Zone of Proximal Development. We allowed students to push their limits of what they knew and only intervened where necessary so that students would be able to move beyond what they already knew.

Another piece of relevant literature for this particular research project is that of Bill Winn entitled, "Beyond Constructivism: A Return to Science-based Research and Practice in Educational Technology." In this article, Winn points out the value of "embodying cognition," that is acting upon our environment by using our bodies and then observing the results. In our activity, students acted on a pre-built robot by reconfiguring the gearing system, observing the results and then acting upon their observations. Winn points out the necessity of students being "present" in the environment, that is "total concentration on the task" (9). Student interaction with the robot and its gearing afforded a similar presence from our student participants. As educators and researchers, we thought it valuable to test an activity that might afford us this kind of "presence" that enhances student concentration and ultimately learning.

Our research team then turned to the writings of Wolfe-Michael Roth, drawing from his article entitled, "Situating Cognition" in order to glean guidance in collecting and evaluating data. Roth suggests that researchers know their "places of interest" well so that they can document and interpret evidence with efficiency (28). Using Roth's concept of figure-ground relations, while observing our activity we looked for instances such as perspectives of participants, changing fields of attention and what was salient as figure to each individual participant. We followed the idea of "zooming" in on the appropriate level and the shifting figure-ground perspectives of our participants. Roth also provides three trajectories or moments of time that should be observed: ongoing activity, change in individual practices, and development of collective practices (31). These were used as a guide in our own observations. Just as Roth assumes that "reasoning is observable in the form of socially structured and embodied activity (34), we proceeded under the same assumption and observed every aspect of interaction.

Method

The students for this activity were two Bellevue Community College students named Breanne and Amber. They were both freshman students at the college who were enrolled in a computer course and they did not know each other prior to the course. They had minimal engineering background and they both said that they covered gears and concepts in the sixth grade but did not remember much of it.

The research setting was a small conference room located on the Bellevue Community College Campus. The conference room was set up to be a learning environment, which included a Lego Mindstorm kit from which a pre-built robot was be provided to the two students. The students were also provided with a gear blocks, axles and three each of four different size gears for a total of twelve gears.

Prior to the activity Breanne and Amber were given a written pre-test in order to ascertain their knowledge of gears and gear ratios. During the activity the two of us were available in order to ask and answer questions on a need-to-know basis. After the pre-test they were given a set of written tasks and reflection questions. These written tasks required that the students do activities with the gears, axels and the gearboxes. All of the activities were hands on in some way and the students were asked to work together to complete the taks.

These tasks included:

1) Investigating and discovering the difference in the gear pieces included in the Lego Mindstorm set.
2) Building different devices that enabled students to discover how the different size gears work differently.
3) Investigating and discovering how the concepts of torque and velocity are related.
4) Reconfiguring the gearing on the pre-built robot so that the is able to climb an incline.
5) After the activity the students were be given a written post-test in order to ascertain their acquired knowledge of gears from this activity.

6) Finally, the students were given a written survey asking them specific questions relating to the effectiveness of the instructional methods.

Results and Data Gathered

Amber and Breanne, began the research activity by first completing a written pre-test in order to assess their knowledge of gears and. The pre-test consisted of seven questions which included questions about gear ratios, gearing up as opposed to gearing down, and torque.

Amber's knowledge of gears was minimal. Of the seven questions, she only answered two questions correctly. Her answers did indicate that she had some idea as to how gears worked and their numbered ratios, but her knowledge was unclear. For example, she transposed her answer 8:24 when it should 'have been 24:8. She also mixed up gearing down with gearing up. Breanne's knowledge of gears was slightly better. She answered three of seven questions correctly but marked one answer with a question mark, indicating that she was unsure of her answer. Neither student noticed (or at least noted) that question number three was a bogus question. It read: What two gears would be used to achieve a ratio of 5 to 2 (5:2) and which of the gears would be attached to the motor? Given the choice of gear sizes, none of the gear combinations would have worked. Neither student was able to recognize this inconsistency in the question on the pre-test.

The students were then given a worksheet that required that they do some activities together and come to a consensus for answers. They were each given a worksheet and told that each student needed to complete a separate worksheet even though they were expected to come up with the same answers. In some instances their answers were not the same on paper even though they appeared to agree upon the same answer during the activity. All of the answers were, however correct although Breanne's answers were more complete.

After completing the worksheet, students were given a written post-test which were the same questions asked on the pre-test. Both students answered five out of seven questions correctly. Both students again failed to recognize that question three could not be answered given the choices of gear combinations. The questions that were incorrect related to gear ratios. Thus, while both students appeared to understand gear ratios during the learning activity, when required to apply the ratio concepts on paper, their knowledge was incomplete.

The student surveys also proved valuable as a data resource. Both students spoke favorably of the activity because of its hands on component to learning. They also liked that the instructor had little interaction, intervening only when the students were "stuck" and wanted help. Both students, however, did not like the "worksheet" portion of the activity. One wrote that she was more of a visual person and learned better by doing rather than visualizing.

The observational data that we gathered is based upon Roth's research. Like Roth, we used and analyzed video tape recordings looking for shifts of fields of attention of our participants and concentrated on the perspectives of our participant-students by "zooming" in on their changing figure-grounds. We looked for patterns in their communication between each other, with instructors and we looked for patterns in their gestures and movements. Following, the practices of Roth, we tried to determine why and how cognition occurred during the activity (156). Roth states, I assume that each moment in time is associated with three trajectories that require different 'lens' openings: on going activity; change in individual practices; and development of collective practices (31).

Video Data and Analysis

The study participants were given a worksheet to complete and various gear parts of the Lego Mindstorm set. Throughout the activity, their figure-ground fields of attention shifted primarily between these two components of the learning environment. They concentrated on their individual gear parts with which they were experimenting or they concentrated on their individual worksheet. This shifted a bit later into the activity but for the most part, was the on-going mode of operation. When either one of the participants was reading or writing something on the worksheet, the worksheet itself was figure at that moment and everything else was background. This is obvious by their different written responses and in some instances their different interpretations of the answer they had just agreed upon. It is only when one of the two of the participants is unsure of herself that the other participant or the instructor becomes figure.

The video also reveals some patterns of the participants' communication that is worth noting. Often times, when either participant suggests a solution or answer to a problem, she asks for confirmation from the other and in rare cases, asks the instructor. Both participants also often follow up their suggestions with a bit of laughter, as if they need the other person to be able to find amusement in their "guess" in case they are wrong. It seems apparent that they look to each other for both moral support as well as intellectual affirmation. At two different points during the activity, each participant expressed concern that the other was ahead of her and the other responded by hesitating and helping the other get to the same numbered item. This was done even though they appeared to be working independently at times since the figure was often their own worksheet or gear pieces.

Their pattern of communication changes dramatically only when the two of them get to a point in the activity where they need the help of the other to complete a task. One of the activities requires that a gear be marked and its revolutions counted. They relied on each other to make an accurate count and even went so far as to count out loud together. The second part of the activity required that one spin a gear while the other attempted to hold the axle in place. To due this, one of them had to put down her own gear parts and her figure had to shift to the other participant's gear parts. This activity was followed by a more complete discussion between the two of them as to what they had observed and learned from the activity. It would seem that this particular question lead to a more collective practice within the learning environment.

The last part of the activity required that the participants change the gears of the pre-built robot so that it could climb an incline. Armed with the knowledge that they had learned in the first part of the activity, they were both anxious to take the robot apart and reconfigure its gears. They both sat on the floor together and shared equally in solving the problem. This too proved to be an activity that enhanced the development of the collective practice within the learning environment.

What the results mean

From the video analysis, one can conclude that this guided discovery activity within a "learning community" was of benefit to both participants. Each looked to each other for moral support and intellectual confirmation. They also found the assistance of the instructor a welcoming interjection at some points of the activity. Students showed interest and enjoyment in being able to interact with the artifacts and with each other. However, despite the collective practices that can be observed surrounding the Lego game pieces, there was still a lot of individualism observable in the interaction with the worksheet and individual games pieces held by the two separate participants. The fact that neither one of the participants liked having to complete the worksheet seems to indicate that they would have preferred more activities that afforded them the opportunity for more collective practices.

Anther form of data, the post-test, shows an improvement in students' understanding of gears, however, the designed lesson could be improved upon in order to improve student knowledge even further. Our design needs improvement since our student participants show that some of the knowledge they learned was indeed 'inert.' Neither student was able to apply the concept of gear ratios when they were presented with a bogus post test question. This seems to prove Ann Brown's point that students must be challenged with critical inquiry during the learning process. Had we included a learning activity that required students to confront bogus ratio applications during the group activity, they may have been able to apply that knowledge during the post testing stage.

We were able to observe how and why our structured environment did provide a system of inter-dependent components: students, instructors, and artifacts, that through the "self-organizing process", did come to "an agreement over an understanding" so that the students' conceptions of gears and gearing concepts" converged towards an agreement with ‘experts,’ that is, their instructors (Bell and Winn, 5). From those observations we were also able to ascertain where improvement and change needed to be made in our environment. Thus, our hypotheses is basically proven and confirmed: Guided discovery learning in a learning community is an effective educational methodology that can be improved upon through operational research. One of the components, the worksheet, seemed to be an effective tool for teaching and guiding the students, however, the students may have lost some “presence” during their interactions with the worksheet since neither student liked having to interact with it. This too, may have some part in the less than 100% score on the post-test.

Recommendations

It is interesting that the students could apply much of the knowledge that they learned about gears, ratios, torque and velocity to the real world situation by changing the gears on a pre-built robot to climb an incline. Yet, when these students were asked to apply these ratios on paper, their knowledge proved incomplete. Perhaps research needs to follow up on educational methods that emphasize hands on application, to the point where students cannot conceptualize these realities using paper and pencil? Perhaps students should be learning how to do both?

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